AN INTERPRETATION OF THE FUNCTIONS OF THE FRONTAL LOBE

Based Upon Observations in Forty-Eight Cases of Prefrontal Lobotomy*

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Ideas concerning the functions of the frontal lobes have undergone a radical change during the past few years. The older hypotheses (which are too well known to require discussion here) were based upon certain conditions such as injuries, tumors, or inflammatory lesions of various types, in which the general effects of disease upon the brain as a whole could by no means be excluded. Moreover, in certain types of disease, the symptoms were more or less the same no matter what the localization. Strauss and Keschner,[14, 18] for example, found a higher incidence of personality changes and mental phenomena in cases of tumors of the temporal lobes than in those affecting the frontal lobes. In recent years neurosurgeons have demonstrated conclusively that either frontal association area may be removed almost in its entirety without producing more than slight defects in the functional capacity of the individual.[12]

The classical account by Brickner[2] of a man in whom both frontal lobes had been extensively resected, followed by similar cases studied by Ackerly,[1] by Karnosh,[13] and by Hebb[8] presented a very striking picture, bringing to a focus the syndrome of frontal lobe deficiency. Brickner attributed to the frontal lobes the function of synthesis of intellectual operations. To quote from his conclusions (page 319): "Only one function is considered as primarily affected. This is the elaborate association or synthesis into complex structures of the simpler engrammatic products associated in the more posterior parts of the brain. There is a diminution in the amount of synthesis, which places a limit upon the degree of attainable complexity of thought. Through this deficiency, the large variety of secondary and tertiary defects becomes manifest, and the overt personality

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appears to be greatly altered. All excepting a small group of symptoms can be explained on the basis of synthesizing capacity . . . While many of the symptoms have an emotional coloring there is nothing to indicate an emotional disturbance in the primary sense." A few pages earlier in his book, Brickner describes and discusses some of the symptoms that do not seem to fit into the rubric "Synthesis," and we find these very illuminating. After alluding to the incontinence and regression in the sexual life, he mentions the loss of distractibility (which was so prominent a feature in Ackerly's case), the presence of compulsive thinking, and later continues: "Perhaps the most mystifying of the special symptoms is the patient's lack of appreciation of the gravity of the situation. This is sufficiently striking in *A* to be out of all proportion to his other defects in appreciation and judgment." Brickner thinks that explanations of this phenomenon might appear too speculative. This lack of appreciation of the gravity of the personal situation appears to us to be evidence of the most important type, and will be dealt with in considerable detail later. In our opinion it supplies the key to the understanding of frontal lobe function.

Prefrontal Lobotomy

During the past three years we[4, 5, 21] have studied 48 patients who have been subjected to prefrontal lobotomy in an attempt to relieve certain disabling neurotic and psychotic states. At first following the technic of Egas Moniz[16] and making discrete lesions in the white matter beneath the frontal association areas of the cortex, we later modified this in order to secure more complete subcortical separation of the frontal association areas.

Operative Technic

In the first 20 cases the technic described by Egas Moniz[16] was employed. A burr hole was made over each frontal lobe 3 cm. lateral to the midline and 3 cm. in front of the interaural line. Six spherical cuts or "cores" were made with a leucotome in the upper part of each frontal lobe. In the next series 9 "cores" were made with the leucotome in the white matter of the lower half of each frontal lobe. When using the Moniz approach it was found that a slight difference in angulation of the leucotome occasionally resulted in making the lesions too near the frontal pole in some instances and too far posterior in others. Another objection to the leucotome method is that it leaves behind "cores" of devitalized tissue, which may act as foreign

bodies. With increasing experience it has been found that better results are obtained when a larger proportion of white matter is cut.

In order to improve the technic the following method was devised. A burr hole is made over the lateral aspect of each frontal lobe through the coronal suture 2.5 cm. above the floor of the frontal fossa. The white matter in each frontal lobe is cut just anterior to the tip of the ventricle in the plane of the coronal suture. The burr hole is located 3 cm. posterior to the lateral rim of the orbit (anterior margin) and from 5 to 5.5 cm. above the zygomatic process. A burr hole placed at this point passes through the coronal suture. The point of intersection of the coronal suture with the interparietal suture is located by making a small incision in the midline about 12 or 13 cm. from the glabella. The dura and pia arachnoid are incised. For purposes of orientation the ventricle is tapped, the median longitudinal fissure and the sphenoidal ridge are identified with the brain canula or leucotome. A nasal septum elevator is inserted into the frontal lobe with the point directed at the burr hole in the opposite side until the end is within 1 cm. of the midline. The white matter in the lower and upper parts of the frontal lobe is cut by swinging the instrument upward and downward in the plane of the coronal suture. Lipiodol or air is injected into the frontal lobe incision and x-rays are taken to verify the location of the lesion.

The operation itself is not a shocking procedure and is relatively painless, so that we have been able to carry out a number of observations while the patients were under local anesthesia. Moreover, the more cooperative patients have undergone fairly comprehensive psychological tests both before and at intervals after the operation, so that we have data upon both the immediate and the remote effects of the operation.

Immediate Effects

The immediate effects of the operation, even though it is not a shocking procedure, cannot offer us much information upon the functions of the frontal lobes. There is probably a diaschisis effect from the abrupt severing of so many axones and collaterals. Actually the patients can converse quite rationally during the operation upon either the right or the left side of the brain, but often as soon as the first incision is made in the frontal lobe on the opposite side, there is immediate abolition of anxiety and nervous tension; the pulse and blood pressure fall within a few minutes, the skin of the extremities becomes warm and flushed, and there is considerable sweating. As the incision into the white matter is made more extensive the patient becomes disoriented, and with the final incision, upward or down-

ward, becomes drowsy or goes into stupor from which he is roused with difficulty and answers in monosyllables.

During the following two or three days or longer there is vesical incontinence, and the sluggish state persists. Neurologic signs other than these are usually absent. The physical condition remains good. The patients are often restless and try to get out of bed, and upon questioning are found to be completely disoriented. These patients present a placidity and indifference that forms a striking contrast to their previous apprehensive state. They answer questions pertaining to their condition mostly in monosyllables, but correctly. They make no effort to eat the food that is placed before them, but continue accepting food as long as the nurse feeds them, chewing and swallowing with precision. There is a peculiar flattening of the voice, with abrupt termination of sentences and inability to carry on a consecutive conversation. Not infrequently the patients pick at the bedclothes or at the dressings, and many of them do not seem to realize that they have been operated upon. They thumb the pages of magazines or look over the newspapers, but are unable to recall what they have read. They show no disturbance of the sleep rhythm. Occasionally they fumble with the genitalia. In certain cases in which the less extensive operation is performed, the patients develop considerable euphoria and talkativeness, but later these patients usually relapse into the abnormal mental condition present before operation. An early return of orientation and vivacity presages failure. Hallucinations and delusions immediately lose their affective component and soon disappear, although some compulsive phenomena continue. One "incurable" (and uncured) alcoholic, persistently hunted beneath his pillow for the bottle that was not there, repeatedly poured himself imaginary drinks, going through the motions of draining his glass. A bacteriophobe persistently brushed the "bugs" from the counterpane. In the immediate postoperative phase, while the patient is still dull and inert, we have occasionally observed an exaggerated startle reaction to a variety of stimuli.

As time passes the patients recover a considerable degree of spontaneity, eating well, and sometimes to excess (one woman gained 90 pounds in one year), reading with pleasure, knitting, sewing, walking about, and talking with other patients while still in the hospital. Orientation returns, but is at times vague. Replies become quicker and more circumstantial, there is occasionally a little confabulation.

If the patient is asked something beyond his powers there is a certain degree of evasion, bluffing, and good-natured wise-cracking, but we have seldom observed any outspoken Witzelsucht. Aggressive phenomena are noted infrequently, but one individual was quite hyperactive, slapping his nurses upon the fundament, pulling fixtures from the walls, and even ringing the fire alarm. In another patient of similar aggressive character previous to operation the unrestrained behavior became manifest after returning home and for months he was not fit to live with, losing his business and alienating his family, all the time being unaware that there was anything peculiar in his behavior. Such examples have been rare, fortunately, and are probably dependent upon the type of individual operated upon.

Remote Effects

Examination of the patient a month or so after operation probably yields the most accurate information concerning the deficit present. At this time the immediate postoperative effects have subsided, and the later compensatory functions have not yet had time for fruition. Indeed, it may require six weeks to a year for patients to recover sufficiently to enable them to resume their occupations at full capacity. When examination is carried out a month after operation it is found that there is a certain inertia present. The patient responds courteously and accurately, but volunteers little. The relatives state that the patient spends most of his time sitting in a chair, not reading or playing games; apparently perfectly at ease, but merely unoccupied. He reacts usually in a satisfactory manner to demands within his capacity, carries on a conversation addressed directly to him, but in a general conversation he is apt to remain silent. The flattening of the voice is somewhat reminiscent of the "plateau speech" of the epileptic. In some cases there is a prolonged flow of speech, it being almost impossible to interrupt the patient before he has completed his train of thought. Then conversation suddenly ceases until started anew. This symptom does not continue overly long. Its genesis is obscure, but it is a fairly reliable guide to the completeness of the operation, and those patients that present it may be assured of persistent relief from their distress. He may spend a long time at his meals or in bathing and dressing, showing no particular perplexity, and following suggestions as to what to do next, carrying through routine procedures more or less auto-

matically, but when one task is finished he does not go on to the next. He just sits. If he makes any complaint it is about fatigue. He seems to lack sufficient energy to carry him onward. On the other hand, this lackadaisical behavior is unaccompanied by any feeling of distress. Patients who formerly at home "made the dirt fly," can look with equanimity at collections of cobwebs and dusty shelves. There is a definite tendency to procrastination. The patients make plans for tomorrow, but somehow, tomorrow never comes. They do enough for today, and then stop. On the other hand, if given a task of more or less repetitive character, they will often continue more or less automatically, beyond the limits of normal patience.

They are not distressed by failure. We had one very marked instance of this in a woman with agitated depression who was unable to make up her mind about anything, and who wept even though she completed correctly some of the test problems. After operation she was unable to complete the same problems, but continued far beyond the patience of the examiner, making mistake after mistake with not the least indication of embarrassment.

A month or two after operation, patients who have undergone prefrontal lobotomy are able to discuss their sensations and emotions quite dispassionately. They can often bring back certain sensorial and ideational activities that were present during the pre-operative phase, but their attitude toward those activities is altered by the absence of any strong emotional component. Thus, a young woman who had been actively hallucinated told in a matter-of-fact way that she could still evoke the image of her husband or of God and his angels merely by thinking of them. "Some of those things were pretty nice," she said with a reminiscent smile. Another patient could remember depressing thoughts in connection with her phobias, but she admitted that she had to turn her attention actively to the subject, and that the obsessive character of the ideas had departed. Hypochondriacal complaints are usually eliminated from the first, and seldom recur. Compulsive motor phenomena, automatic patterns of behavior, tend to subside much more slowly.

Symptoms Relieved Do Not Indicate Normal Functions

It would be unjustifiable to assemble this rather bewildering array of phenomena and to claim that the disappearance of this or

that sign or symptom was proof that the frontal lobes initiated this or that function. One might as well term the frontal lobes the centers for dissatisfaction or of fear, or to say that they are the centers for obsessive thinking or hypochondria. Only by inference can some idea of the function of the frontal lobes be gained. In cases of frontal lobe injury, probably more than in any other condition, it is erroneous to argue from symptoms due to destruction directly to matters of function of the destroyed parts. This method of reasoning was severely and justifiably criticized by Hughlings Jackson[10] in connection with his studies on aphasia.

To take up first the intellectual functions, it has been shown by Jacobsen[11] in rigidly controlled animal experiments, that there is a strong temporal factor concerned in frontal lobe function. Problems can be solved by lobectomized apes provided that all the elements for the solution are presented simultaneously. This is his conclusion after studies on the delayed response reaction, which is severely impaired in these animals. As a positive deduction one might state that the function of the frontal lobes is to retain in consciousness simultaneously a number of concepts differing in temporal relationships. We observed a telephone operator who demonstrated this rather conclusively. Her postoperative record in regard to completion of calls was above average and upon repeated observation she made no mistakes. On the other hand, she was supposed, as each call was completed, to push a button recording the call. She failed to record some 30 per cent of the calls. Apparently she could respond correctly to the stimulus, but was unable to keep in mind the further operation of recording it.

Brickner[8] emphasized the function of synthesis, and has reported a case that shed much illumination upon this function. A banker who was developing a tumor of the frontal lobe found himself unable to gather together the various details of procedure in connection with the filing of papers for the transfer of property. Penfield[17] has also called attention to this in speaking of a deficiency in planned initiative, as a phenomenon following excision of one frontal lobe for tumor.

There is an active component in both of these concepts, although expressed more or less in the negative. While the patient with frontal lobe defects may be incapable of synthesis of engrams, or of planned initiative, it is probably beyond the scope of the argument to declare that the frontal lobes furnish the motive power, the initiative,

the energy of response of the personality. Indeed, both animals and men deprived of their frontal lobes in large degree are apt to reveal a diffuse and irregular spontaneous activity or restlessness without obvious motivation. It must probably be admitted that the motive force of the personality lies in other parts, and is possibly diffusely represented in the brain, the frontal lobes exerting a sort of directive orientation upon the essential flow of kinetic energy. Just what this directive orientation is will be suggested presently.

Autonomic Phenomena

Autonomic phenomena following lobotomy will be considered very briefly. Urinary and fecal incontinence, flattening of the voice, and lowering and stabilizing of the blood pressure are frequently observed. The incontinence is the type characterized by sudden involuntary emptying of the bladder. The patients are aware of the act, but unable to foresee it. They pay "lip service" to better control but assume no responsibility for it. They say, "I lost control" or "I wet myself." Regular visits to the toilet meet with more success than persuasion or criticism. Langworthy and Kolb[15] have shown that cortical lesions, especially when bilateral, cause signs of release of the bladder reflexes with increase in the response to stretch. Watts and Uhle[23] have studied the problem in clinical cases of brain tumor, confirming the observations of Langworthy and his colleagues on hyperexcitable bladders. In man the "hypertonicity" or "spasticity" of the bladder manifests itself in urgency, limited capacity, and violent contraction when the bladder is filled or when urine collects. Bladder disturbances are often present a week, but may last two or three months after lobotomy.

Fecal incontinence, which is sometimes observed during the immediate postoperative course, is probably the result of a peristaltic rush in the large intestine due to release of the cortical mechanism which normally regulates gastro-intestinal movements.[19, 20, 22] The appetite improves, but in contrast to monkeys with extirpation of both frontal association areas, there is a gain in weight in our patients.

In patients with hypertension the systolic blood pressure may be lowered as much as 60 to 80 mm. of mercury, but this great reduction is not permanent. In other patients who suffer with cold hands and feet, the circulation to the extremities improves, but the mechanism for peripheral vasoconstriction is not lost as indicated by the

recurrence of cold hands in response to anxiety. That blood pressure and peripheral circulation are regulated in some degree by the cortex is known. In reviewing the experimental studies Fulton[6] points out that faradic stimulation of certain regions of the dog cortex may evoke primary elevation in systolic blood pressure of as much as 80 to 110 mm. of mercury. Depressor points are also present in the cortex very close to pressor areas. Green and Hoff[7] have demonstrated that the cerebral cortex is capable of initiating a direct shift of blood from the visceral to the muscular bed. Probably the abolition of fear by the operation is responsible for the observed tranquilization of the circulatory system.

We have too few observations upon the sex function to make worthwhile a report of this function.

Emotional Activities

That the frontal lobes are greatly concerned in emotional activities can barely be doubted from observations of these patients. We recently observed an individual who became extremely apprehensive during the operation under local anesthesia. He was quite restless upon the table, asking that the covers be raised so that he could breathe, requesting sips of water, and grasping the hand of the nurse at every opportunity. He was unable to carry on a coherent conversation because of his intense anxiety. The pulse rose to 140 and the blood pressure to 145 during the cutting of the fibers on one side. With the first cut on the opposite side his anxiety left him, the pulse dropped to 80 and the blood pressure to 110, and although he was unable to carry on a conversation, he admitted that all fear and anxiety left him.

The emotional activity of the frontal lobe is apparently due to its relation with the thalamus. The anterior thalamic peduncle is a heavy band of fibers constituting the anterior limb of the internal capsule, and by fibrillary dissection this bundle can be seen to originate (or terminate) in the medial nucleus of the thalamus, running between it and the frontal pole.[9] The more anterior portions are difficult to follow on account of the inter-weaving with the fibers of the corpus callosum, but by splitting the white matter along the lines of the anterior limb of the internal capsule, the direction of these fibers can be traced quite definitely toward the frontal pole. It is more or less generally believed at the present time that the thal-

amus, particularly its medial nucleus, is concerned with affective tone. That a considerable degree of affect is still present in these lobotomized patients is indicated by one individual of very lachrymose habits previous to operation who was completely relieved of her agitated depression by the operation. About four days after the operation the nurse who had been with her constantly in the home for a year or more died suddenly. When the patient was informed of her death she broke out into very natural tears and lamentations, showing a normal response. But the tears were soon dried, and from that time on the patient wept no more.

Apparently, this patient (and others of similar type) reacted adequately to emotional situations arising outside of the individual, but much less to intrinsic situations, such as frustration, doubt, guilt, indecision, etc., that arose within the individual.

Since it is not the emotions themselves that are affected by prefrontal lobotomy, there must be another component referable to the frontal lobes that is involved. It might possibly reside in the image of the total individual and the affect attached thereto. This brings us to the crux of the hypothesis of frontal lobe function.

Hypothesis of Frontal Lobe Function

The cerebral cortex may be considered as being divided by the Rolandic fissure into two portions of essentially different function. The parts posterior to the fissure are concerned with the reception of impulses from receptors of various sorts situated all over the body, and with the elaboration of those impulses into engrams. By means of various association centers and pathways, the individual is brought by the post-rolandic cortex into relation with all that has gone before in his existence. Experience and intelligence, the bases of his behavior, are mediated by this part of the brain.

Just as the post-rolandic cortex is concerned with the past, the pre-rolandic cortex is concerned with the future. Aside from certain small areas that are concerned with the direct execution of muscular movements and the regulation of visceral function, the rest of the frontal cortex is, according to our hypothesis, concerned with the projection of the whole individual into the future. With the intact brain the individual is able to foresee, to see before, to forecast the results of certain activities that he is to initiate in the future. And he can visualize what effect those actions will have upon himself and

upon his environment. One patient expressed this concept almost directly. He was the man who slapped his nurses and pulled the fire alarm. "Now that I have done it," he said, "I can see it was not the thing to do, but beforehand I couldn't say whether or not it would be all right." A patient with intact frontal lobes can presumably define the goal toward which he is working, and estimate more or less clearly the nearness with which he approaches it. By projecting himself into the future in his "mind's eye" he is calling upon his cortical mechanisms to synthesize past experience as a guide, and upon his emotional mechanisms for driving force, the search for satisfaction, and the avoidance of distress. Once the goal is set he is further calling upon his cortical mechanisms to assemble the various parts of the problem and to select the proper course among the many alternatives that present themselves to him at the completion of each separate step. Corollary follows theorem in logical anticipation, and total behavior is modified in response to changed conditions. Satisfaction or dissatisfaction depends upon the recognition of the nearness that actuality approaches to the ideal that he has foreseen.

Synthesis, planned initiative, and the "social sense" described by Bianchi, are thus brought under the same larger heading, and to this is joined the recognition of the self by the self, the factor that proved puzzling to Brickner. Insight demands that the individual shall erect in his mind an image of himself in relation to the outside world, and he can do this only if he projects himself into the future and sees himself as he should appear. In so doing he also compares this image with that obtained from evidence furnished by his senses once the act has been accomplished.

If this hypothesis is accepted it makes more easily understandable many of the observed facts concerning frontal lobe disease. Inertia and lack of ambition, reduction in consecutive thinking, loss of what is commonly called self-consciousness, indifference to the opinions of others, satisfaction with performance even though this may be of inferior quality; these may be considered as among the primary results. Euphoria, evasion, bluffing, talkativeness, moria, aggressive behavior, teasing, indecency in speech and act, inattention, poor judgment; these might be classed among the secondary results.

Is it possible from consideration of the hypothesis enunciated above, to arrive at any better understanding of the neuroses and psychoses, their genesis, their mechanism, their course? We believe so, but such a discussion would carry us too far afield. It need only

be mentioned that the idea of projection into the future reaches much the same conclusion from the physiologic standpoint that the concept of the super-ego reaches from the psychologic standpoint. In this respect the physiologic and psychologic concepts of the mind can be said to approach one another more closely than before.

Conclusions

From a study of 48 cases of prefrontal lobotomy the conclusion is reached that the frontal lobes are concerned with the projection of the individual-as-a-whole into the future, with the formation of an image of the individual-as-he-is-becoming. The other suggested functions appear to be mechanisms by which this is attained. Many of the symptoms of frontal lobe disease can be explained upon the basis that the individual has lost his self-critique, is more easily satisfied, is lacking in "social sense," has had an impairment of his imagination as related to himself. The frontal lobes are not centers of intelligence nor of emotion, nor are they directly concerned with the energy drive of the individual. They assemble the available data, synthesize them, plan a course of action with the ideal in mind, and, equipped with energy of response and with appropriate affective tone, project the individual into the future, direct him toward his goal—and criticize his shortcomings.

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